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REMOVAL OF POLLUTANTS USING RADIAL AND VERTICAL FLOW REGIME REACTORS

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ABSTRACT

Batch and continuous processes were conducted to study the adsorption of methylene blue dye on to three adsorbent materials, commercial activated carbon, chemically activated corncob carbon with phosphoric acid and ion exchange resin (akualite). Batch processes were established to show the effects of solution pH, contact time, adsorbent dosage, agitation speed and initial dye concentration. Two isotherm models, Freundlich and Langmuir fitted with the experimental data found from batch processes, the Langmuir model fitted well than the Freundlich, with maximum adsorption capacities of 16.21, 30.95 and 77.52 mg/g and R^2 *of 0.952, 0.992 and 0.995 predicted by commercial activated carbon, corncob activated carbon akualite respectively. Series of column test for the three adsorbent materials at different three flow rates (0.2, 0.3 and 0.4 L/min) and three initial dye concentrations (15, 30 and 50 mg/l), the same volume of (775 ml) from adsorbent materials used for both radial and vertical reactors to make a comparison between the capacity of the adsorbent materials each with another and between the performance of radial and vertical flow regime reactors configurations on breakthrough curves behavior. Radial flow regime reactor showed good results in comparison with vertical flow regime reactor.*

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1. INTRODUCTION

Pollution caused by industrial wastewaters has become a common problem for many countries. Dyes and pigments are one of the problematic groups of pollutants. Wastewaters discharged from different industries such as the textile, leather tanning, paper production, food technology, hair colorings, etc. are usually polluted by dyes (**Hameed and El-Khaiary, 2008**). It is estimated that more than 100,000 commercially available dyes with over 7×10^5 tons of dyestuff produced annually. Major problems associated with colored effluent are lowering light penetration, photosynthesis and damages the aesthetic nature of the water surface (**Mohammed et al., 2014**).

Dyes usually have complex aromatic molecular structures which make them more stable and difficult to biodegrade. Moreover, direct discharges of synthetic dyes into urban wastewaters in natural environments may cause the formation of toxic carcinogenic breakdown products.

The presence of small amount of dyes (less than 1ppm) is highly visible and undesirable (**Zainol, 2010**). Methylene blue (MB) is an important basic dye widely used for coloring paper, temporary hair colorant, coating for paper stock, dyeing, printing cotton and tannin, dyeing leather, used as an antiseptic and for other medicinal purposes (**Idris et al., 2012**). MB can cause eye burns, and if swallowed, it causes irritation to the gastrointestinal tract with symptoms of nausea, vomiting and diarrhea. It may also cause methemoglobinemia, cyanosis, convulsions and dyspnea if inhaled. There for, the removal of such dyes from effluents prior to their final discharge is of significant environmental, technical, and commercial (**Yan and Wang, 2013**). Treatment of dye-based effluents is considered to be one of the challenging tasks in environmental fraternity (**Himakshi et al., 2013**). There are many removal techniques such as chemical oxidation, precipitation, filtration, aerobic and anaerobic microbial degradation, coagulation, membrane separation, electrochemical treatment, flotation, hydrogen peroxide catalysis, and reverse osmosis, ozonation and biological techniques can be employed to remove various pollutant form the textile industry wastewater (**Gonawala and Mehta, 2014**).

However, some of these methods are non-economical and have many disadvantages such as high reagent and energy requirements, generation of toxic sludge or other waste products that require disposal or treatment. Among several chemical and physical treatment methods, the adsorption has been found to be superior to other techniques for the removal of dyes from aqueous solution in terms of methodology, operational conditions and efficiency (**Fungaro et al., 2010**). Activated carbon is widely used as an adsorbent due to its high adsorption abilities in removal of organic pollutants from wastewater (**Olivella et al., 2012**). The use of carbon as an adsorbent is limited because of its high cost. At present, there is a growing interest in using low cost adsorbents for dye adsorption. If an adsorbent is inexpensive and ready for use, the adsorption process will be a promising technique (**Gong et al., 2008**). The abundance and availability of agricultural by products make them good sources of raw materials for activated carbon (**Taha et al., 2014**). Corn is a significant crop which can be found all around the world. The annual production worldwide is about 520×10^9 kg. Corncob as a biomass and agricultural waste is an attractive candidate. Usage of these biomass wastes as a raw material for production of activated carbon is a highly beneficial (**Wang et al., 2010**). Adsorption of dye using ion exchange resins is a practical method for the removal of dyes from wastewaters and recycling water when compared with the widely used adsorption onto activated carbon. Its main advantages

are as follows: the ion exchangers are not lost during the regeneration, recovery of the process water, and the removal of soluble dye (**Kauspediene et al., 2013**).

In designing new internal arrangements to achieve a radial flow it is imperative that the flow distribution obtained in the radial inward flow direction is as near ideal as possible. This is harder than for a classic axial flow reactor because of the increased problems of inlet flow distribution and also because of the inherently lower pressure drops through the bed. The advantages of radial over axial flow reactors are the high flow capacity, low pressure drop, and the possibility of using finely divided catalysts (**Li and Zhu, 2011)**. The packed column of radial flow chromatography (RFC) consists of two concentric porous cylindrical sieves, between which the stationary phase is filled with an adsorbent (**Dia et al., 2009**).

2. EXPERIMENTAL WORK

2.1. Adsorbate

Methylene Blue (MB) dye was used as an adsorbate in the present study. The choice of MB dye as an adsorbate is due to its known strong adsorption on to solids. The MB dye used was by supplied by Sigma-Aldrich, scientific bureaus in Iraq, Bagdad. A stock solution of methylene with 1000 mg/l concentration was prepared by dissolving 1 gm of powder in 1 L of distilled water, other required concentrations were prepared by diluting.

2.2 Adsorbents

2.2.1. Commercial Activated Carbon

Granular activated carbon supplied by Iraqi markets with effective size of 1mm was used as an adsorbent material. Sieve analysis obtained using British standards in Kufa University, civil engineering laboratory. Carbon was washed with distilled water for several times to remove all impurities and then dried in electric oven for two hours at 110^{o} C to exclude any moisture content.

2.2.2. Corncob Activated Carbon

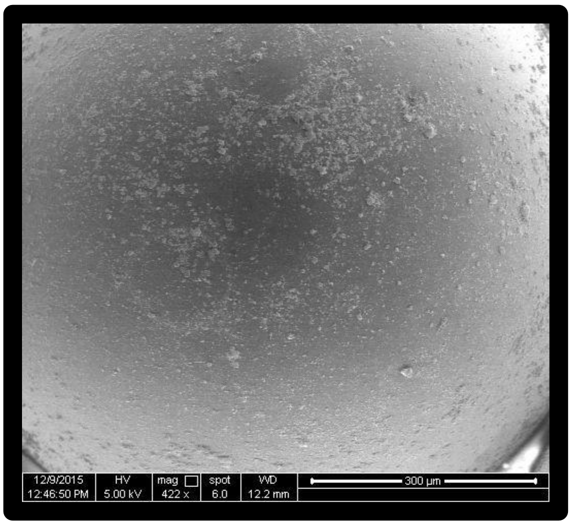
Corncob activated carbon was prepared as following (**Rocha et al., 2015)**

- Collection of the corncobs from Babylon Governorate.
- Cutting and sieving of collected corncobs to size near to 1 mm
- Washing and drying of sieved corncobs for two hours at 110°C.
- Soaking of dried corncobs with 0.85% solution of H_3PO_4 at a ratio of one mile of H_3PO_4 to one gram of dried corncobs for two hours
- Heating of soaked corncobs for two hours in an oven at 400 °C.
- Cooling and washing of produced activated carbon with distilled water until pH of washings reached to 6.
- Finally drying of product activated carbon at 110°C for two hours.

2.2.3. Akualite (Ion Exchange Resin)

Weak acid cation exchange resin of model C-107E (Acualite) with the following properties, polymer matrix structure of macroporous polymath acrylic cross linked with divinely benzene, functional group of carboxylic acid ($-COO^-$), shipping weight (g/L) of (700–730), operating pH range from 5–14, Maximum operating temperature

of 100^0 C, Total exchange capacity (equiv/L, equiv/kg) of dry resin (13.7, 9.4). Acualite was supplied by scientific bureaus in Iraq, Bagdad. Figure (3) shows the SEM of akualite before and after adsorption of MB dye. Figures 1 and 2 show the SEM of akualite and produced activated carbon respectively.



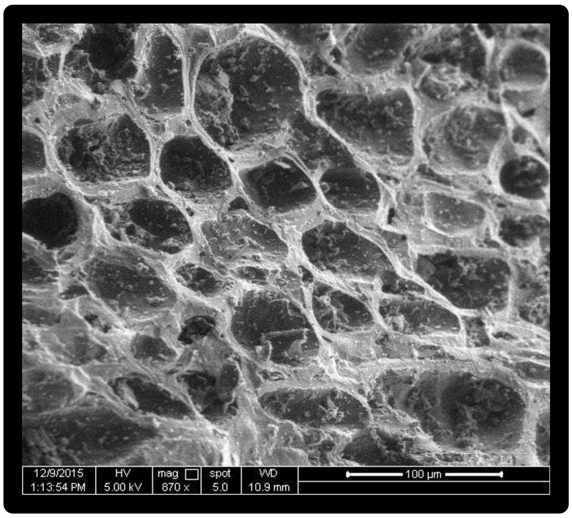


Figure (1) SEM of akualite **Figure (2)** SEM of produced carbon

2.2. Experimental Arrangement

2.2.1. Radial Flow Reactor

Radial flow regime reactor with flow from external to center pipe was designed by perforated external and internal pipes located inside back house acrylic reactor. The external and the internal pipes have a diameter of 10 and 1cm respectively and a height of 16 cm. Back house acrylic reactor has an inner bottom and top diameters of 14.5 cm and 16.5 cm respectively. The adsorbent forced in between the external and internal pipes with effective depth (depth in the direction of the flow) equal to (radius of external pipe 10/2 – radius of internal pipe-1/2) 4.5cm and height equal to 10 cm. The same volume of (775 ml) from adsorbent materials (commercial activated carbon, corncob activated carbon and ion exchange resin) used for both radial and vertical reactors in continuous flow processes.

2.2.2. Vertical Flow Regime Reactor

Vertical flow regime reactor with down flow direction was established in a column of (8.5cm) inner diameter and (80cm) height. The two ends of column were provided with plastic sieve of (0.5cm) diameter followed by mesh layer of (0.2mm) diameter to provide good distribution of flow and to prevent materials form out flow respectively. The column was packed with the adsorbent of 13.7 cm height between two supporting layers. Above and bottom of the adsorbent there were (5cm) layer of gravel to prevent adsorbent from float and to provide a good distribution of flow, these two layers of gravel were washed after each run and used for all runs without replacing to ensure that there is no partition in adsorption process. Figures (3) and (4) show radial and vertical flow reactor respectively.

Figure (3) Radial flow reactor

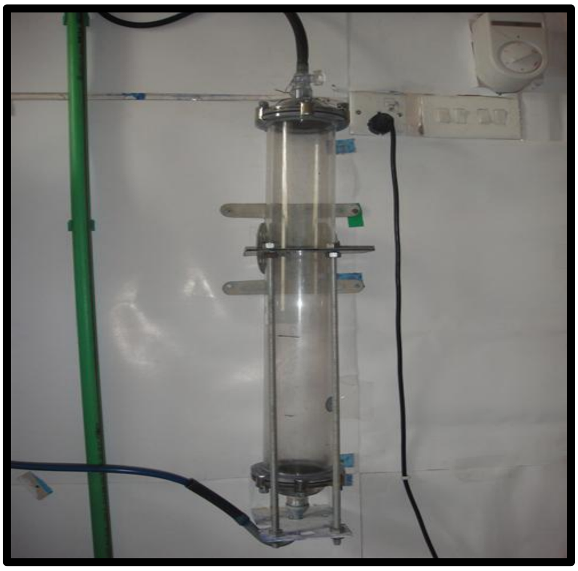


Figure (4) Vertical flow reactor

3. BATCH EXPERIMENTAL RESULTS

Batch processes are important examples in which the adsorbent moves relative to the walls of the contaminated vessel. The simplest process involves a specific volume of wastewater is mixed with a quantity of adsorbent into a container until the pollutant decreased to desired level for a certain period of time. Batch experimental processes were conducted to study the effect of various parameters, such as the pH, contact time, adsorbent dose, agitation speed and initial dye concentration for commercial activated carbon, corncob activated carbon and ion exchange resin (Akualite). Batch experimental processes established in bottles of (250 ml) of volume, containing a (100 ml) of methylene blue solution.

3.1. Effect of Solution pH

One of the important factors that affecting the capacity of adsorbent in treatment is the solution pH. The efficiency of adsorption is dependent on the solution pH, since variation in value of pH leads to the variation in the degree of ionization of the adsorptive molecule and the surface properties of adsorbent (**Nandi et al., 2009**). The effects of pH on adsorption of methylene blue (MB) dye for commercial activated carbon, corncob activated carbon and akualite were evaluated using parameter shown in table (1).

Table (1) adopted parameters for pH effects evaluation

Item Material	Dose (g)	Time (hr.)	speed (rpm)	Co (mg/l)
Commercial carbon	0.5	10	250	100
Corncob carbon	0.5	5	250	100
Akualite	0.25	4	270	100

It can be seen (Figure 5), for commercial activated carbon, when the pH increased from 2 to 6 caused an increase in removal efficiency from 74 to 79% respectively, decreasing in adsorption efficiency from 78 to 72 % when pH increased from 7 to 12, the maximum removal efficiency of 79% monitored at pH 6. For corncob activated carbon, when the pH increased from 2 to 7 caused an increase in removal efficiency from 80.6 to 94.3% respectively, decreasing in adsorption efficiency from 92.8 to 80.6 % when pH increased from 8 to 12, the maximum removal efficiency of 94.3% monitored at pH 7. For akualite, when the pH increased from 2 to 10 caused an increase in removal efficiency from 85.45 to 97% respectively, approximately, constant removal efficiency in pH (8, 10 and 12), the maximum removal efficiency of 97% monitored at pH 10.

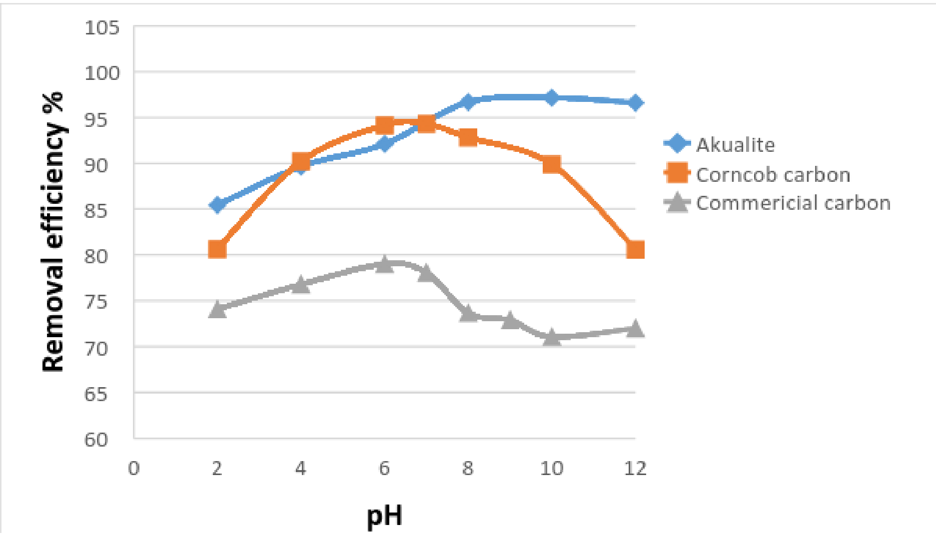


Figure (5) The effects of pH on MB adsorption on to commercial activated carbon, corncob activated carbon and akualite

3.2. Effect of Contact Time

The effect of contact time shown in figure (6) was investigated to find equilibrium time of adsorption using the parameters shown in table (1) except of time and pHs of 6,7 and 8 as optimum values for commercial activated carbon, corncob activated carbon and akualite respectively. It is clear for three adsorbent that the rate of

adsorption is rapid at the beginning and becomes slow in later stages till saturation is reached. It is basically due to the saturation of the active sites which do not allow further adsorption to take place. The equilibrium times are 8, 5 and 1.25 hr. for commercial activated carbon, corncob activated carbon and akualite respectively.

3.3. Effect of Adsorbent Dosage

The effect of the amount dose on the MB dye adsorption was examined using the parameters shown in table (1) of the agitation speed and the initial dye concentration, with amount of dose from 0.25 to 1.5 g for commercial and corncob activated carbon and from 0.1 to 1 g for akualite, optimum pHs values and contact time of 8, 5 and 2 hr., for commercial activated carbon, corncob activated carbon and akualite respectively. As shown in figure (7) the increasing in adsorbent dosage from 0.25 to 1.5 mg, 0.25 to 1 and 0.1 to 0.7 resulted in an increase of removal efficiency from 59 to 98.56%, 72.73 to 99.99 % and 76.5 to 99.99% for commercial activated carbon, corncob activated carbon and akualite respectively.

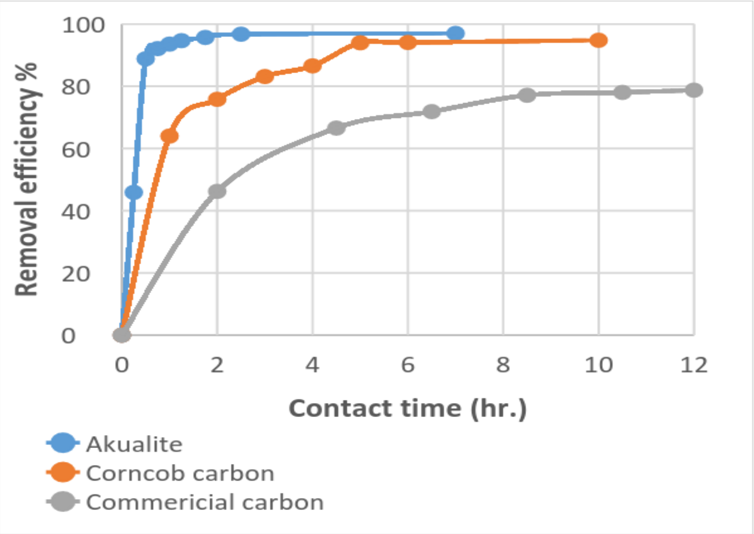


Figure (6) The effect of contact time on adsorption of MB dye onto commercial activated carbon, corncob activated carbon and akualite

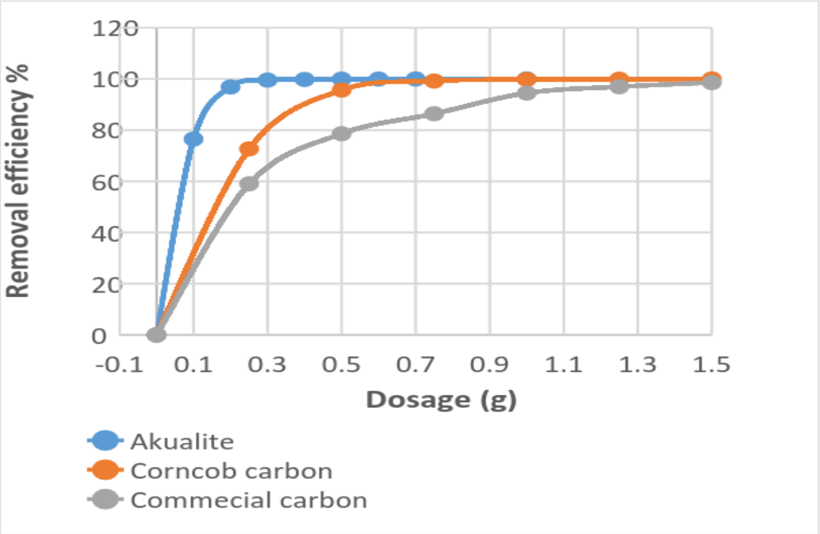


Figure (7) the effect of amount dosage on adsorption of MB dye onto commercial activated carbon, corncob activated carbon and akualite

3.4. Effect of Agitation Speed

The effect of agitation speed on the equilibrium adsorption was conducted as shown in figure (8) using the parameters shown in table (1) of the dosage and the initial dye concentration, optimum pHs and contact times found from pervious steps and different agitation speeds ranging from 50 to 300 rpm. For commercial activated carbon, when the agitation speed increased from 50 to 150 resulted in an increase of removal efficiency from 43 to 75%, approximately constant removal efficiency of 78% in speeds above than 200 rpm. When the agitation speed increased from 50 to 150 resulted in an increase of removal efficiency from 51 to 88% and from 60 t0 91%, approximately constant removal efficiency of 93 and 96 % in speeds above than 250 rpm for corncob activated carbon and akualite respectively. This behavior due to the increase in turbulence and the decrease in boundary layer thickness around the adsorbent particles.

3.5. Effect of Initial Dye Concentration

The effect of initial dye concentration on MB dye adsorption was evaluated as shown in figure (9) using the parameters shown in table (1) of the dosage and the agitation speed, optimum pHs and contact times found from pervious steps and different initial dye concentrations ranging from 50 t0 250 mg/l. When the initial dye concentration increased from 50 t0 250, the removal efficiency decreased from 89 to 55, 99.5 to 78.6 and from 99.64 to 86.8 for commercial activated carbon, corncob activated carbon and akualite respectively.

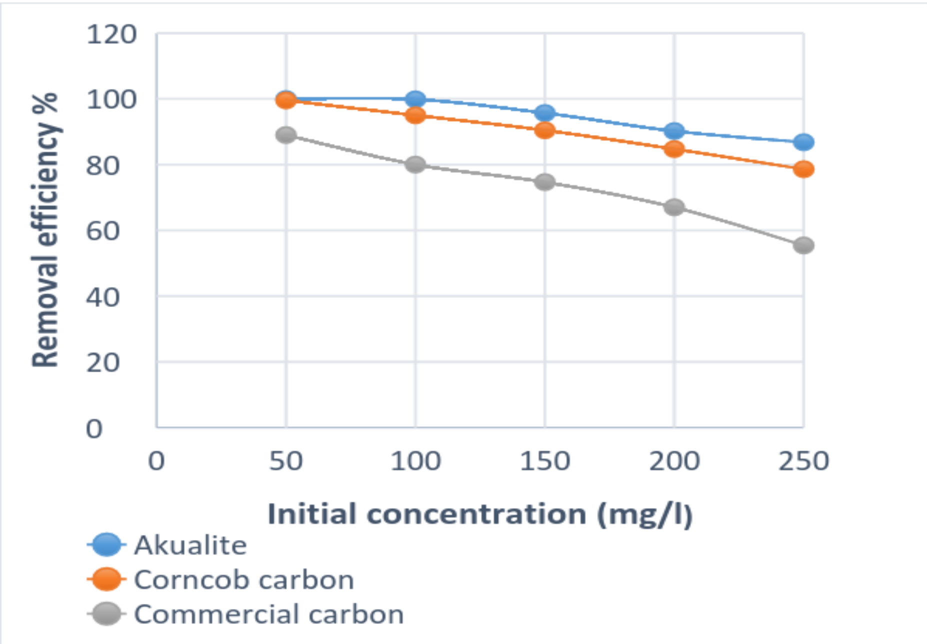


Figure (8) the effect of agitation speed on adsorption of MB dye adsorption on to commercial activated carbon, corncob activated carbon and akualite

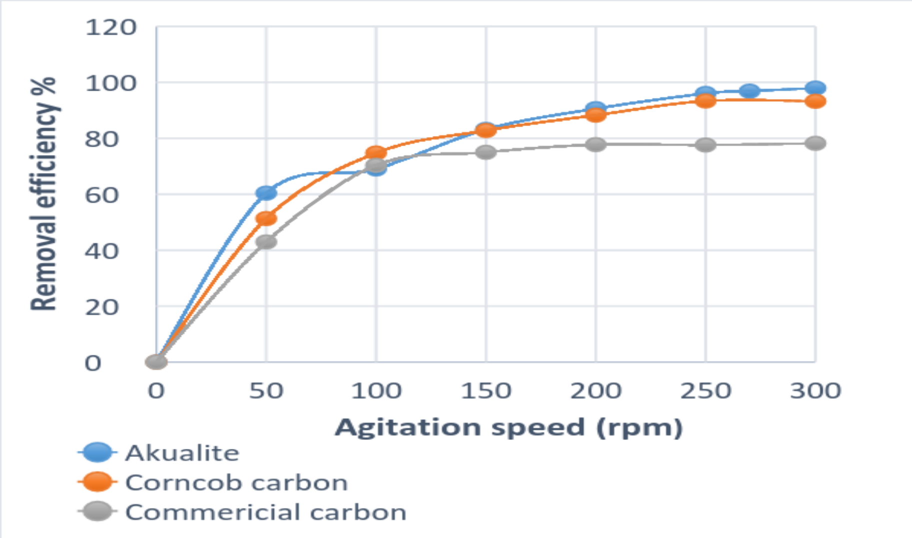


Figure (9) the effect of initial dye concentration on MB dye adsorption for commercial activated carbon, corncob activated carbon and akualite

3.6. Adsorption Equilibrium Isotherms

The adsorption equilibrium isotherms were represented by the Langmuir and the Freundlich isotherm models for adsorption of MB dye on to commercial activated carbon, corncob activated carbon and Akualite. Figures (5.5) and (5.6) show the Langmuir and the Freundlich isotherms reported for adsorption of MB dye on to commercial activated carbon at pH 6, contact time 8 hr., agitation speed 250 rpm, initial concentration 100 mg/l and dosage from 0.5 to 1.5 g. Langmuir and the Freundlich isotherms conducted for adsorption of MB dye on to corncob activated carbon at pH 7, contact time 5 hr., agitation speed 250 rpm, initial concentration 100 mg/l and dosage from 0.5 to 1.5 g as shown in figures (10) and (11).

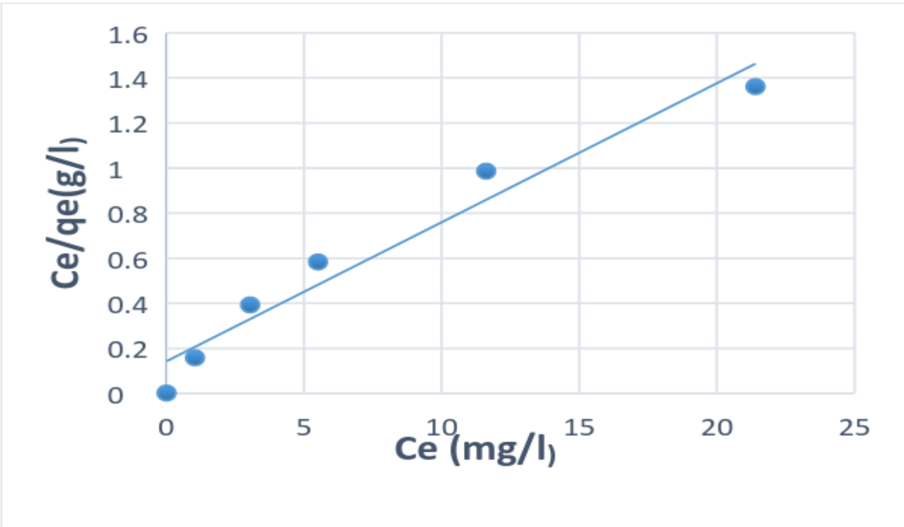


Figure (10) Langmuir isotherm for adsorption of MB dye on to commercial activated carbon

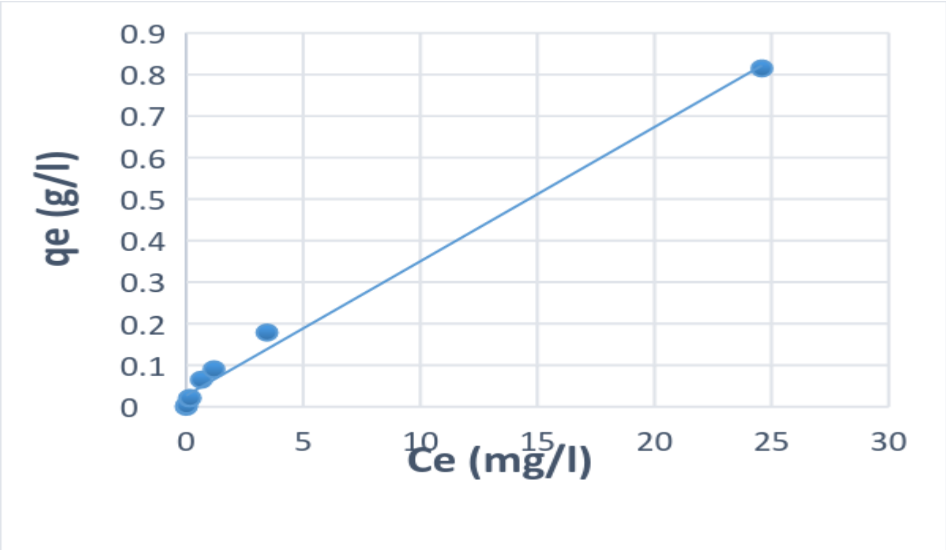


Figure (11) Langmuir isotherm for adsorption of MB dye on to corncob activated carbon

Figure (12) show the Langmuir isotherm reported for adsorption of MB dye on to akualite at pH 8, contact time 2 hr., agitation speed 270 rpm, initial concentration 100 mg/l and dosage from 0.1 to 1 g.

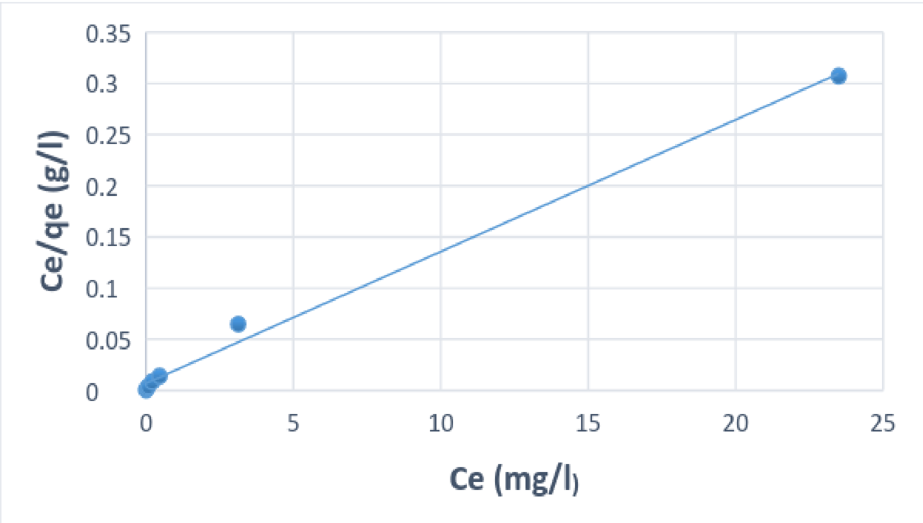


Figure (12) Langmuir isotherm for adsorption of MB dye on to akualite

4. COLUMN EXPERIMENTAL RESULTS

For all three adsorbents (commercial activated carbon, corncob activated carbon and akualite) and both the radial and vertical regime reactors, the flowrates Q =0.2, 0.3 and 0.4L/min and a concentration dye Co=15mg/L were studied as shown in figures (13), (14) and (15).

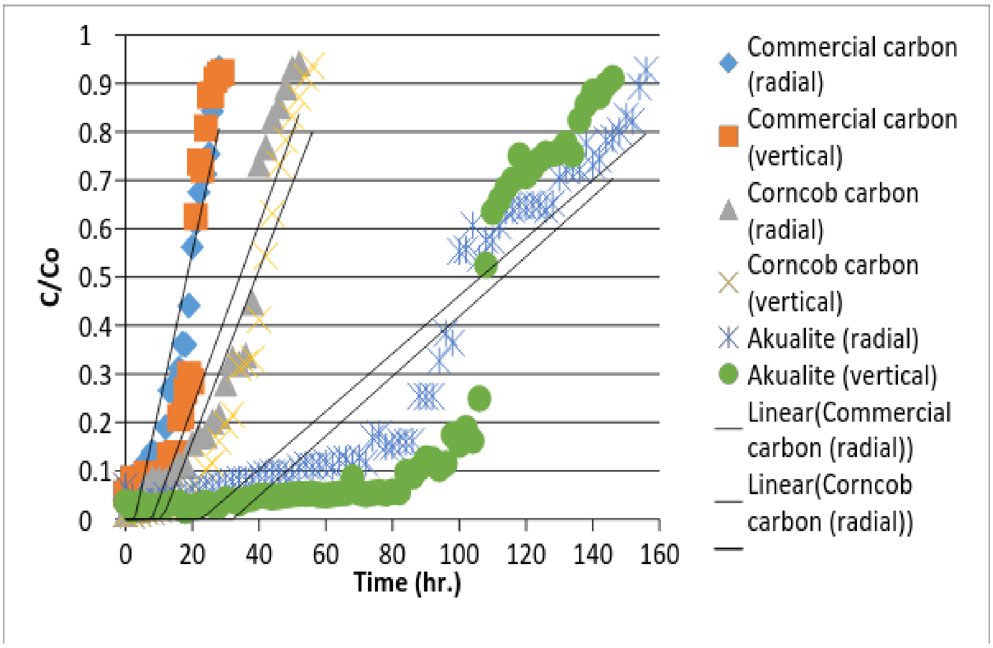


Figure (13) Breakthrough curve for radial and vertical flow regime reactors at Co=15 mg/L, Q= 0.2L/min and pHs 6, 7 and 8 for MB dye adsorption onto commercial activated carbon, corncob activated carbon and akualite respectively.

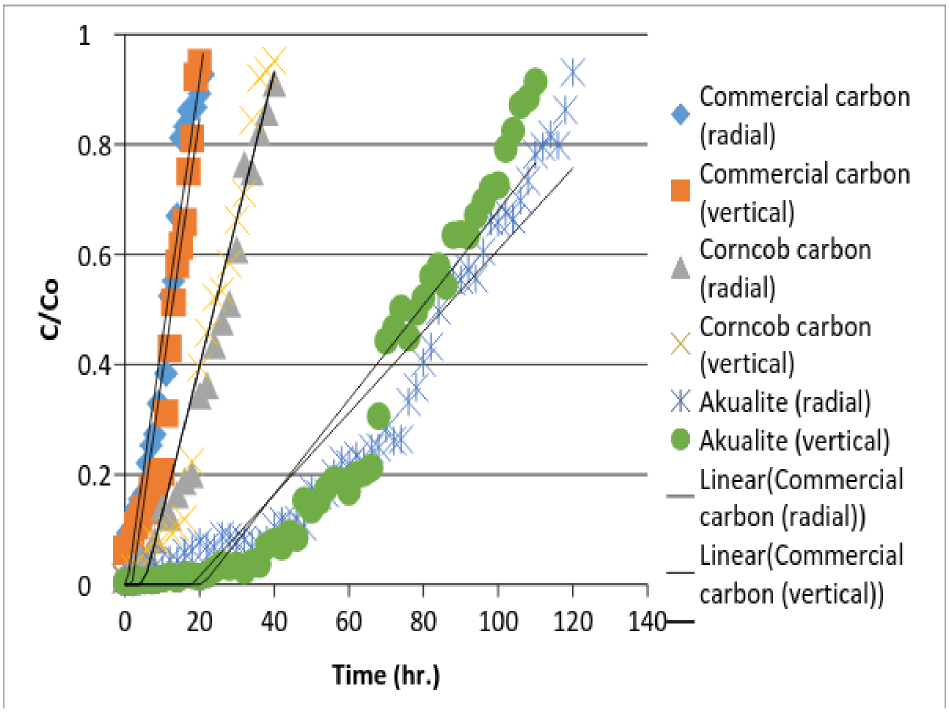


Figure (14) Breakthrough curve for radial and vertical flow regime reactors at Co=15 mg/L, Q= 0.3L/min and pHs 6, 7 and 8 for MB dye adsorption onto commercial activated carbon, corncob activated carbon and akualite respectively.

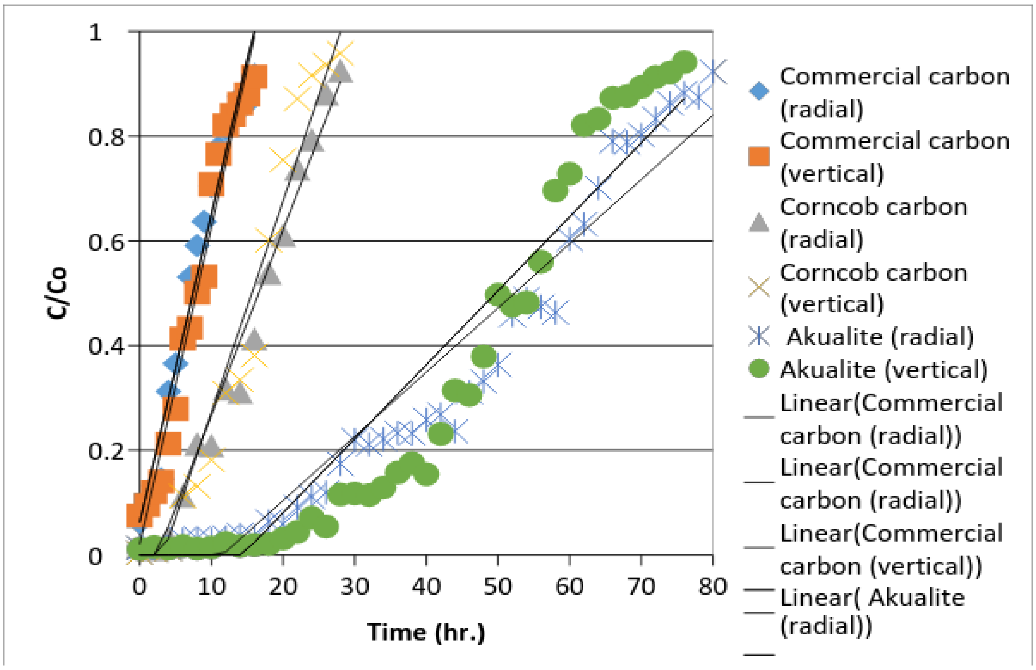


Figure (15) Breakthrough curve for radial and vertical flow regime reactors at Co=15 mg/L, Q= 0.4L/min and pHs 6, 7 and 8 for MB dye adsorption onto commercial activated carbon, corncob activated carbon and akualite respectively.

5. CONCLUSIONS

Based on results of batch and continuous processes and simulation of flow obtained from the present study, the following conclusions can be written:

- The optimum achieved parameters for methylene blue dye adsorption are: solution pHs of 6,7 and 8, contact times of 8, 5 and 1.25 hr., adsorbent dosages of 1.5, 0.5 and 0.25 gm, agitation speeds of 200, 250 and 270 rpm and initial dye concentration of 50 mg/l exhibited by commercial activated carbon, corncob activated carbon and akualite respectively.
- Langmuir model fitted well with the experimental data, with maximum monolayer adsorption capacities of 16.21, 30.95 and 77.52 mg/g and R^2 of 0.952, 0.992 and 0.995 predicted by commercial activated carbon, corncob activated carbon akualite respectively.
- In radial flow regime reactor, breakthrough curves showed that the outlet concentration of methylene blue dye at the beginning of run time is higher and the break point time is larger in comparison with vertical flow regime reactor for most figures of breakthrough curve.
- The results of continuous flow processes showed that, when the flow rate or initial dye concentration increase, the time required reaching saturation decreases for both radial and vertical regime reactors.
- Convergence in the time required reaching saturation between the radial and vertical regime reactors, as the flow rate or initial dye concentration increase in the results of continuous flow processes.
- Radial flow regime reactor may be a competitive installation over vertical flow regime reactor in removing of MB dye from aqueous solution.

- For commercial activated carbon and corncob activated carbon, the time required to reach the ratio C/Co =0.9 is approximately 20% and 40% respectively of the time required for akualite to reach the same ratio of C/Co.
- Chemically activated corncob carbon showed good adsorption capacities in comparison with commercial activated carbon, while akualite exhibited good adsorption capacities than commercial activated carbon and corncob activated carbon in both batch and breakthrough curve studies.
- Corncob is a good agriculture source for activated carbon production utilized for MB dye adsorption in comparison with many agriculture materials utilized for dyes removal.

REFERENCES

[1] Dai Y., Wang J., Jia S., Yue S., Jia M. and Xu P., (2009), "Study on the Purification of Polysaccharides from Noscoc flagelliforme with Radial Flow Chromatography", Biotechnology and Bioprocess Engineering, Vol.14, pp 377-382

[2] Fungaroa D.A., Groschea L.C., Pinheirob A.S., Juliana C. Izidoroa, J.C. and Borrely, S.I., (2010), "Adsorption of methylene blue from aqueous solution on zeolitic material and the improvement as toxicity removal to living organisms" electronic journal of chemistry, Vol. 2, No. 3

[3] Gonawala K.H. and Mehta, M. J., (2014), "Removal of color from different dye wastewater by using ferric oxide as an adsorbent" Engineering Research, Vol. 4, Issue 5

[4] Gong R., Zhu S., Zhang D., Chen J., Nia S. and Guan R., (2008), "Adsorption behavior of cationic dyes on citric acid esterifying wheat straw: kinetic and thermodynamic profile", Desalination 230 pp 220–228

[5] Hameed, B.H. and El-Khaiary, M.I., (2008) "Malachite green adsorption by rattan sawdust: Isotherm, kinetic and mechanism modeling" Hazardous Materials, Vol.159 pp 574–579

[6] Himakshi, Neelakshi and Meena, R. C., (2013), "MBIR DOWEX-11 assisted photocatalytic degradation of azo dyes: A review" Sci. Revs. Chem., Vol.3(4), pp 181-189

[7] Idris, S., Ndamitso, M.M., Iyaka, Y. A. and Muhammad, E. B., (2012), "Sawdust as an Adsorbent for the Removal of Methylene Blue from Aqueous Solution: Adsorption and Equilibrium Studies", Chemical engineering Vol. 1, No. 1

[8] Kauspediene D., Kazlauskiene E., Cesuniene R., Gefeniene A., Ragauskas R., Selskiene A., (2013), "Removal of the phthalocyanine dye from acidic solutions using resins with the polystyrene divinylbenzene matrix", chem. vol. 24, No. 3, pp 171–181

[9] Li R. and Zhu Z., (2011), "Investigations on hydrodynamics of multilayer –type radial flow reactors", Chem. Eng. Vol. 7, pp 517–527

[10] Mohammed, M.A., Shitu, A. and Ibrahim A., (2014), "Removal of Methylene Blue Using Low Cost Adsorbent: A Review", Chem. Sci. Vol. 4(1), pp 91-102

[11] Olivella M.A., Fiol N., Torr F.D., Poch J. and Villaescusa, I., (2012), "A mechanistic approach methylene blue sorption on two vegetable wastes: cork park and grab stalk" bioresources 3340-3354

[12] Rocha P.D., Franca A.S. and Oliveira L.S., (2015), "Batch and column studies of phenol adsorption by an activated carbon based on acid treatment of corn cobs", IACSIT, International Journal of Engineering and Technology, Vol. 7, No. 6.

[13] Taha D.N., Samaka I.S., Luma Ahmed Mohammed L.A. and Saib A., (2014) “Adsorption Studies of Direct Red 28 Dye onto Activated Carbon Prepared from Low Cost Material” Civil and Environmental Research, Vol.6, No.7

[14] Wang Y. X., Liu B. S., and Zheng C., (2010), “Preparation and Adsorption Properties of Corncob-Derived Activated Carbon with High Surface Area”, Chem. Eng. Vol. 55, pp 4669–4676.

[15] Prof. Dr. Mohammad Abid Moslim Al-Tufaily and Zahraa Ali Hmoud. Using of Wasted Filings of Iron To Adsorb Methylene Blue Dye From Aqueous Solution, *International Journal of Advanced Research in Engineering and Technology*, **5**(4), 2014, pp. 57-67.

[16] Yan, T. and Wang, L., (2013), “Adsorptive removal of methylene blue from Aqueous Solution by spent mushroom substrate: Equilibrium, kinetics and thermodynamic” J. of Bioresources, Vol. 8(3), pp 4722-4734

[17] Zainol, N. I. B., (2010), “Biosorption of iron (II) and methylene blue using tea waste”, Thesis, Faculty of Chemical and Natural Resources Engineering, University of Malaysia.

[18] Prof. Dr. Mohammad Abid Moslim Al-Tufaily and Wisam Sh. Jabir Al- Salami. Computerize Rcra, Ewc and Bc Hazardous Wastes Classification System Using Visual Basic- 6 Language, *International Journal of Civil Engineering and Technology*, **5**(1), 2014, pp. 111-124.